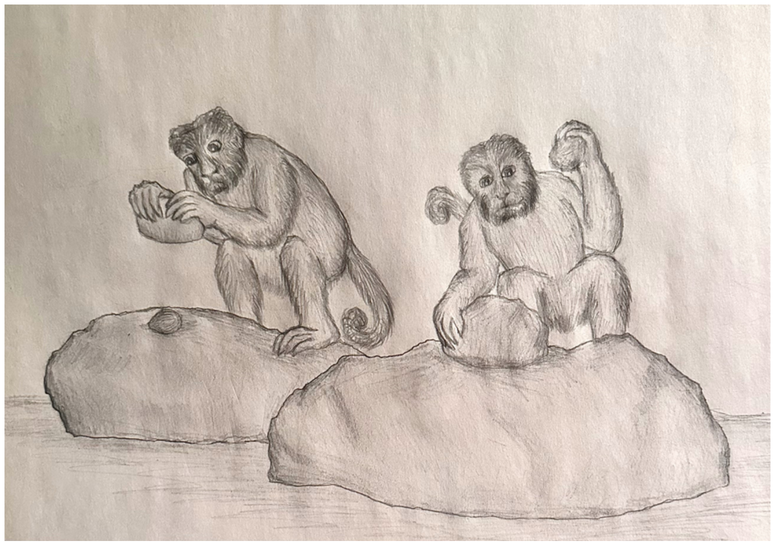
Stone tools and our primate relatives: A comparative analysis with human lithics and predictions for the future

by Prithvi Singh Kahlon



Within three millennia, capuchins appear to have made substantial progress in their use of stones relative to other living non-human primates, including the great apes. The rapid evolution of capuchin tool use can help us better understand unclear aspects of our own evolutionary journey; it can also inform us of the decisions we may have to make regarding how we will share our planet with this primate in the future. However, no prior literature has comparatively examined capuchin and human lithics within naturalistic contexts to subsequently tackle the issues of pre-Clovis validity and future capuchin stone use. Therefore, I first review secondary data on the lithic items that capuchins have been interacting with over the last 3000 years in the first section of this paper. Subsequently, I discuss the similarities between present-day capuchin-made lithics and human flintknapping attributes. Essentially, capuchins have become proficient in the motor-skills required to detach flakes from stones in a manner somewhat similar to Oldowan hominins. However, capuchins do not modify these flakes; they use them expediently as a source of mineral nutrition or as hammerstones for percussion activities. In the second section of this paper, I examine literature related to archaeologically controversial sites that supposedly suggest human presence in the Americas predating 12,000 years ago. In particular, I compare capuchin lithics with secondary data from one Mexican site and one Brazilian site to argue whether the stone items at the two sites were made by: 1) neotropical primates; or 2) the forces of nature. Based on my discussion of capuchin lithic activities from past to present, I make a conjecture in the final section of this paper that the right set of conditions could enable modern capuchins to potentially begin intentionally detaching flakes for tool use over the next few centuries.

Prithvi Singh Kahlon is a BA Student at the University of Alberta (Department of Anthropology, 13–15 HM Tory Building, Edmonton, Alberta, T6G 2H4 [pkahlon@ualberta.ca]).

Graphical abstract is an illustration courtesy of P. S. Kahlon.

Humanity had long considered the act of toolmaking in itself to be solely under its dominion until primatologist Jane Goodall (1964) revealed the existence of both perishable and non-perishable tool use among the great apes. However, the general ideology of our exclusive technological prowess still persists today, and it does hold some merit. After all, chimpanzees have purportedly been engaging in lithic activities for many millennia but have made marginal progress in their technological capabilities over that period of time (Falótico et al. 2019). However, a different player in this grand game of evolution had been working away undetected on its lithic materials and underwent a dynamic shift in its material culture over a relatively short amount of time: the capuchin. Several groups have investigated these New World simians in efforts to map out their past and document their present relative to our own, which I will discuss in the first section. In the second section, I apply this investigation of our distant monkey cousins to the debate around pre-Clovis inhabitation of the Americas, which may shed more light on the issue and work towards resolving the controversy behind some archeological sites. Lastly, the increased study of capuchin behavior in relation to stone tool use will lead us to have an improved understanding of the concept of evolutionary pace. Capuchins provide a stark contrast to the notion that evolution takes tens of thousands and millions of years to occur, for they have evolved over a span of centuries and millennia. Thus, lithic tool use in non-human primates is pivotal in providing insight into human evolution and our ideas of evolutionary pace; consequently, greater analysis on our evolutionary relatives will enable us to contemplate their future advancements and will pave the way for others to discuss implications for our coexistence.

What Our Primate Relatives Have Been up To

Over the last two decades, numerous aspects of non-human primate tool use have come to light that are shaping our current views on the nature of evolution itself. Here, I will focus my discussion on bearded capuchins (*Sapajus libidinosus*)—who I will often refer to as simply "capuchins" throughout this paper—and chronicle their technological journey over the span of three millennia. Subsequently, I will delve into the present-day lithic activities of these primates.

Capuchin Lithics of Antiquity

In Serra da Capivara National Park, Brazil, Tiago Falótico and colleagues (2019) undertook stratigraphic excavations at the Caju BPF2 site and discovered that capuchins have their own archaeological record, one that stretches back 3,000 years. Falótico and his team performed radiocarbon dating on a total of fifteen charcoal pieces (Supplementary Information: 7). Based on their dating-results, the capuchin archaeological record of 122 lithic items can be compartmentalized into four distinct phases at the Caju BPF2 site: Phase IV (earliest), Phase III, Phase II, and Phase I (most recent). Each of these phases varied in duration significantly, with Phase IV easily comprising the longest period at the site. Furthermore, sediments may have deposited very little in the area during certain parts of the site's lifetime, which may be the reason for gaps in the capuchin story, with pockets of time unaccounted for. The group of researchers also acknowledged that the capuchin lithic record could entail either one of two scenarios: 1) the occupation of multiple capuchins groups with different stone use "cultures"; or 2) the occupation of a single capuchin group that evolved in their use of lithic usage. In other words, either scenario is equally plausible according to Falótico and his team, but the authors leaned toward the likelihood of the latter. I will utilize this latter scenario to provide a brief narrative of capuchin lithic technologies at Caju BPF2.

In Phase IV, around the year 2993 Cal BP, capuchins apparently began utilizing stones present in the area now called Caju BPF2. Here, these simians gravitated toward smaller, lighter stone objects such as photograph (e) in Falótico et al.'s (2019) Figure 2, which they could use to access small food items enclosed within shell-like structures. Such food items in Phase IV were likely easier to access and not as hard as those found in later phases; thus, capuchins had little need for big hammerstones when attempting to extract food from various sources. As a result, the small stone items that the capuchins in Caju BPF2 used more than two millennia ago received a great deal of percussion, distinctive damage from the percussion activities, and significant use-wear patterns through the extensive use of these stones. For the next couple of centuries, the capuchin population in the Caju BPF2 area underwent a period of transition in their technology from 640–565 Cal BP as the monkeys continued engaging in percussive activities while simultaneously beginning to implement large anvils in their lithic usage.

Around the time of 257–27 Cal BP, the lithic technological behaviors of capuchins began to shift dramatically in the frequency with which they utilized stone anvils. The sizes for anvils and hammerstones also increased as the simians progressed into Phase II. Essentially, the capuchins had fully integrated large stone anvils like the item in photograph (c) of Falótico et al.'s (2019) Figure 2 in their lithic usage by this point of their evolutionary history, with their eyes set on harder foods beyond the cashews and other nuts to which they had long been accustomed. Then, over the last 100 years or so, the capuchin population at the Caju BPF2 site began to return to easier food sources such as cashews; thus, large stone anvils and hammerstones began to diminish in usage over this region during Phase I. Nonetheless, the overall hammerstone sizes that capuchins of Phase 1 utilize are noticeably larger than those from the earliest known phase at the site, Phase 4, thereby indicating an overall increase in the size of lithic objects that capuchins have interacted with over the millennia.

Habitual Lithic Activity among Capuchins in Boa Vista

In another part of Brazil, a different group of individuals investigated the various aspects related to hammer and anvil stones utilized by capuchins. Elisabetta Visalberghi et. al (2007) essentially found a key aspect of capuchin tool use among the populations in Boa Vista. They noted the plethora of anvil stones situated near one another throughout the varied regions of Boa Vista, whether currently in use or abandoned. Furthermore, the anvils themselves exhibited extensive signs of usage with the presence of numerous shells around these stone items, and little depressions known as use-wear pits covered the surfaces. The prevalence of anvils in the Boa Vista landscape in conjunction with the substantial use-wear signs on the stone items suggests that the capuchins engaged in both habitual as well as long-term stone tool use, as indicated by the use-wear extent on the anvils, which likely represents the multiyear usage of a given anvil. Moreover, the presence of habitual stone usage in Boa Vista capuchin populations supports the idea that the long-term lithic activities of this species are not niched to one region such as the Caju BPF2 site but can be generalized to other locations as well.

Two years later, in 2009, Visalberghi and her team opted for a more controlled approach to the analysis of capuchin stone tool use by conducting an experiment on wild capuchins living in the same region. They tested eight wild capuchins, and they accounted for certain factors that could skew results, namely stone-type, number of available stones, and the nuts available. In addition, they left the capuchins with a select number of all the necessary objects. Essentially, the researchers manipulated the size and weight variables for the stone items in order to expose the capuchin subjects to different conditions to reduce any confounding variables. When testing the eight capuchins to see what stone they would pick when faced with two stones of the same size but different weights (Same Size-Different Weight), they found that capuchins tended to choose the lighter (functional) stone for nut-breaking. However, if given a choice between two different-sized stones with the smaller stone weighing more (Conflicting Size and Weight condition), the simians tended to pick up the smaller stone instead for their nut-breaking tasks, a reflection of this interesting species' tendency to prioritize functionality regardless of weight relative to their body size.

In fact, Madhur Mangalam's (2018) dissertation on bearded capuchins in the Fazenda Boa Vista region demonstrates that the small-bodied primates frequently utilize massive hammerstones that are greater than 50% of their body mass, which Mangalam asserts as being far heavier proportionally than the hammerstone-weights that other primates such as chimpanzees and long-tailed macaques work with. Here, Mangalam cites previous research that indicates the chimpanzees lift stones less than 20% of their body-mass during their lithic activities and long-tailed macaques only work with stone items less than 10% of their body-mass. In other words, capuchin monkeys are able to work with a wider range of lithic items relative to their primate brethren because they do not allow heaviness to inhibit stone use in their daily lives. Evidently, the tendency of capuchins to utilize heavy stone objects relative to their body size offers them a selective advantage in various tasks, as observed in the experiment by Visalberghi et al. (2009), and hints at their greater adaptability in the utilization of stone items relative to other primates. Moreover, the use of heavy hammerstones serves as an explanation for the earlier observations by Elisabetta Visalberghi and colleagues (2007) of the prevalence of larger hammerstones in the Boa Vista region as well as the observations by Tiago Falótico's (2019) team of numerous large-sized hammerstones at the Caju BPF2 site.

Similarities between Present-day Capuchin Lithics and Fundamental Flint-Knapping Attributes

In 2016—a few years prior to the discovery of the ancient archaeological record at Serra Da Capivara National Park—Tiago Falótico was part of a team that had examined capuchin lithic activity on a different site but in the same general region, and subsequently released their findings. During that year, Tomos Proffitt and colleagues (2016) made a pivotal revelation at the Oitenta site regarding the present-day activities of our neotropical primate relatives: capuchins flake stone tools. Their paper on the aforementioned discovery included different figures with photographs of various capuchin-modified-stones; there are a total of 111 such stones at the site. However, while reading Proffitt et al.'s (2016) paper, I observed the lack of a fundamental, linear breakdown of the similarities between the lithics of capuchin populations at Serra Da Capivara National Park and basic stone-features that encompass the domain of human flintknapping. Such a comparative analysis would be beneficial to concisely distinguish genuine human lithic achievements from that of our primate brethren or the forces of nature. Therefore, I selected particular photographs of capuchin stones from Tomos Proffitt et al.'s (2016) text for analysis and compared them with universal human lithic patterns that underlie the existence of all hominin stone tools, ranging from distant prehistory to the present day.

One particular stone item of significance is in Proffitt et al.'s (2016) Figure 2 (c), which exhibits several characteristics diagnostic of basic flakes. Flakes that are detached from an originally intact rock—known as an objective piece—will typically consist of two distinct sides: dorsal and ventral (Shea 2013). The ventral surface is simply the inner-side of the flake that detached from the objective piece, and the dorsal surface is the opposite side that represents a portion of the original rock's outer surface. Cortex refers to an original stone's chemically or mechanically weathered outer surface, and the first flake that detaches from an objective piece will tend to be largely cortical dorsal surface, simply known as dorsal cortex. In contrast, ventral surfaces are characteristically devoid of weathering effects because they represent a portion of an objective piece's inner rock. Based on these fundamental concepts, the artifact in Proffitt et al.'s (2016) Figure 2 (c) consists largely of dorsal cortex and appears to be oriented with the proximal end facing downward and the distal end up. I say that the upper region depicted in the photograph is the distal end based on the fact that the bottom surface of the respective stone item is substantially broader in relation to the top half of the artifact, which suggests that the artifact was flaked from the end that is oriented downward toward the upper half of the stone specimen. A definitive characteristic of flakes is that they tend to taper off toward the distal end, not grow in magnitude, as evidenced by both photographs and illustrations of unambiguous hominin flakes in numerous pieces of literature. For example, William Andrefsky Jr.'s (2005) text on the macroscopic attributes of stone tools demonstrates the tapering effect through several illustrations of flake artifacts, including four flake termination-types: feathered, hinge, step, and plunging. Terminations are essentially the shape of a stone flake's distal end, which reflects the manner in which a flake detached from a core-stone during stone percussion. Hinged terminations occur when the impact force from a toolmaker's percussion activity bends away from a core at the time of detachment (Andrefsky 2005), thereby culminating in a rounded or blunted distal end. The illustrations corroborate the idea that the flake specimen presented in diagram (c) of Figure 2 was indeed initiated from the flat surface and detached in a manner that resulted in the distal end becoming rounded. In other words, the artifact consists of a hinged termination.

If the bottom is indeed the proximal end of the artifact, then it must consist of a striking platform. As for the platform-type, there are four main categories to assess from: abraded, complex, cortical, and flat (Andrefsky 2005). Abraded platforms demonstrate signs of sanding/grinding effects on the proximal surface. In contrast, complex striking platforms consist of multiple, tiny, flaked surfaces, called facets. Since cortex is the outer, weathered surface of a rock, a cortical platform is one that includes the weathered surface. Lastly, flat striking platforms are characterized by the presence of one smooth surface with no tiny, separate facets unlike their complex platform counterparts. The possibility for the striking platform to be of the abraded-type can be clearly ruled out since there are neither any apparent signs of sanding/grinding effects on the proximal surface nor any observed behavior of capuchins that demonstrated the presence of stone-grinding activities at any point in Proffitt et al.'s (2016) article. Additionally, the platform cannot be complex either due to the fact that the platform's surface does not consist of any separate facets whatsoever. Furthermore, the textural appearance of the platform is distinct from the stone's dorsal cortex. Therefore, this stone item's platform likely belongs to the flat category.

The stone item in Figure 2, photograph (e) of Proffitt et al.'s (2016) text also demonstrates fundamental attributes associated with human lithic activity. Once again, it appears that the artifact has been oriented with the proximal end facing down and the distal end facing up. The first diagnostic characteristic that I detected on the artifact in this photo was the significant portion of dorsal cortex on the lithic artifact, similar to the previous stone item I inspected. This stone artifact, however, has a cortical striking platform. Since the distal end is the point tapering out as shown by the top-middle picture in photo (e), the end opposite the top is clearly the proximal end. Furthermore, the distinction between the ventral and dorsal surface is fairly clear as well since the dorsal surface has a smoothened, mechanically or chemically weathered appearance that aligns perfectly with the definition of dorsal cortex. Therefore, since the bottom end of the artifact (as oriented in the picture) is the proximal end and has a continuation of that weathered surface, it definitely falls into the category of cortical. The sketch in the bottom half of the photograph explicitly details the surface morphology near the proximal end for the top-right picture. Based on this sketch, the stone artifact evidently has undulations slightly further toward the distal end running through the ventral surface. Additionally, the termination on the artifact's distal end does not end abruptly or become rounded at the distal point at which the margins intersect with one another, a fundamental characteristic of step terminations (Andrefsky 2005). The termination is evidently feathered due to the fact that it trails off at the distal end.

Despite the similarities between the capuchin lithics at Serra da Capivara National Park and the basic modification patterns found on all human lithics, capuchin flakes are apparently an accidental product of their lithic activities (Proffitt et al. 2016). This is not to say that the act of stone-breakage itself is unintended, because the group of capuchins at the Oitenta site do indeed utilize hammerstones to detach particular lithic objects from rock-beds—which I shall refer to as “target-stones”—as well as break/crush a portion of the surfaces of said lithic objects. However, the additional flakes that capuchins produce during the “stone on stone” percussion-activities are essentially due to the inadvertent chipping of lithic fragments from their hammerstones and the target-stones. That being said, these New World monkeys still tend to lick the ventral surfaces of the accidental flakes and even utilize some of the detached pieces as hammerstones themselves. Simply put, the flakes that the capuchins unwittingly detach evidently serve a purpose that is expedient because the monkeys do not reshape any stone items; rather, they simply use and discard them as necessary, which aligns with Andrefsky’s (2005) definition of expedient tools.

Further in the article by Proffitt and colleagues (2016), the authors present additional photographs of capuchin-modified stone tools in Extended Data (Figure 3). Here, I examined photograph (**c**) and found numerous attributes that lie within the stone toolmaking territory. The attribute that I will focus on here is the type of core reduction strategy that appears to be present on the stone from the photograph. Several core reduction strategies exist in the human archaeological record, but the one of relevance with respect to this photo is centripetal reduction. Essentially, this reduction strategy involves multidirectional flaking during a lithic item’s modification process in order to attain the largest sizes of detached flakes as possible, as opposed to as many flakes as possible (Andrefsky 2005). In other words, this strategy favors size over quantity. In fact, Levallois core reduction has also been known to utilize the centripetal method in toolmaking by detaching around a core’s perimeter toward the center of the stone item. Andrefsky provides an illustration of the technique in his Figure 7.6. Hammerstones are also being utilized as cores in the capuchin population in Serra da Capivara National Park because the definition of a core is essentially a stone item that serves as an objective piece from which stone material is typically detached (Shea 2013); in other words, a core is a stone item that mainly serves as a raw-material source for lithic material (Andrefsky 2005).

However, another distinctive strategy for reducing cores is well-documented in the archaeological record, and that is parallel reduction. In contrast to its centripetal reduction counterpart, parallel reduction is a type of core reduction strategy that involves unidirectional flaking of a core-stone with the aim to detach the largest quantity of stone-pieces as possible (Andrefsky 2005); simply put, the parallel reduction technique prioritizes quantity over size. Andrefsky provides a side-by-side comparative illustration of the centripetal and parallel reduction techniques. Since the observations by Tomos Proffitt et al. (2016) were indicative of the fact that the capuchins detached flakes from the hammerstones mainly for the purposes of licking the ventral surfaces of said detached pieces (85), it follows that capuchins would prefer to utilize the centripetal reduction strategy when detaching flakes off their hammerstone as opposed to the parallel approach. Capuchins may potentially be seeking some nutrients from the ventral surfaces of flakes in attempts to compensate for some mineral deficiency. Therefore, it would be more beneficial for these primates to flake off a larger portion of a hammerstone in order to access minerals within it over a larger surface area than to hassle themselves with unnecessarily tinier portions of nutrients on smaller ventral surfaces of numerous detached pieces.

Notwithstanding the potential benefits that the centripetal core reduction method would offer capuchin monkeys, the stone item in Extended Data Figure 3 is simply a hammerstone from which the simians have managed to accidentally detach pieces during the process of repeated percussion against stones lodged within rock-beds (Proffitt et al. 2016). As discussed earlier, all capuchins in natural contexts lack the ability to intentionally detach flakes from objective pieces; their true intention—based on the findings by Proffitt et al. (2016)—appears to be to break open the target-stones. Consequently, they decided to term the core-replicas as "flaked hammerstones", an apt name to describe their true function. Due to their haphazard methodologies, the capuchins evidently have not been able to replicate any lithics that would resemble the parallel reduction technique, which would require the systematic preparation of a striking platform, removal of a flake in the direction perpendicular to the striking platform, and subsequent removal of flakes adjacent to the location of previous flake-removals in the same direction. Essentially, the flaked hammerstones either lean toward the appearance of a centripetally reduced core-stone or do not resemble any definitive core-stone and reduction method typology.

Thus, since our neotropical simian relatives possess the ability to unintentionally modify stones in a manner that provides an uncanny resemblance to that of the act of stone-knapping by our hominin ancestors, some diagnostic stone-knapping signs commonly attributed to humans no longer hold the validity they once did in affirming our technological prowess during the stone age.

The Validity of North/Central/South American Archaeological Sites in Light of Other Primate Tool Use

Based on the evolving lithic usage of our simian relatives, there is a genuine question as to how credible certain archaeological sites previously claimed to be human in origin really are. I will address two such sites that are currently undergoing scrutiny as to the nature of their origin: 1) the Vale da Pedra Furada in Piauí, Brazil; and 2) the Chiquihuite Cave in Mexico.

Brief Overview

Essentially, Vale da Pedra Furada, Piauí, Brazil is a site that is located in an area of sandstone rockfall. The valley floor at this site continues to undergo erosion, but the talus is no longer affected by this geological activity (Boeda et al. 2014). Eric Boeda et al. (2014) indicated that the quantity of purported artifacts at the site substantially increased as they excavated further into the layers of sediment at this site. Regarding the assemblage itself, Boeda and his team claimed that essentially the flaked stone material found at this site is of human origin that extends the presence of humans to earlier than 16,000 Cal BP. Similarly, Ardelean et al. (2020) excavated the Chiquihuite Cave site in Mexico and concluded that the area must have provided refuge to prehistoric humans during a time far earlier than the Last Glacial Maximum.

Chiquihuite Cave's Incompatibility with Either Human or Capuchin Lithics

Both Vale da Pedra Furada and Chiquihuite Cave have numerous critics, including myself, for an array of reasons. B. A. Potter et al. (2021) and J. C. Chatters et al. (2021) critiqued the Chiquihuite Cave site by addressing the nature of the site itself: a place of heavy water flow and stones comprising the roof of the cave that could easily have contributed to the so-called "human" stone items found at the site. Simply put, the line of logic in the rigorous critiques by Potter et al. (2021) and Chatters et al. (2021) is that rocks from the ceiling could have periodically detached and fallen, fractured upon impact, and been displaced by the flowing water within the cave to the location where they would eventually settle until excavators would recover them many thousands of years later. Chatters and colleagues brought into question the legitimacy of the stones themselves by stating that these lithic items mainly lacked systematic retouch (which is the modification of a flake's ventral surface) and consistent location of flake scars (because the scars on the cave stones were randomly placed). In other words, the purported artifacts were missing the various diagnostic characteristics associated with genuine human tools. Moreover, B. A. Potter et al.'s (2021) critique of Chiquihuite Cave highlights the fact that Ardelean and colleagues (2021) have glossed over the sporadic assortment of lithic material in the sediment layers as well as a total lack of any hearths/activity areas, lithic material from beyond the cave despite the availability of "high quality toolstone" in the vicinity, and material-culture evolution over a span of 20,000 years. Lastly, there was no correlation between the kinds of animal remains found in this cave with those of Paleoindian diets of the time.

Although critics of the Chiquihuite Cave in Mexico suggested that the stone-pieces were produced by natural processes, it is imperative to consider whether capuchins could have made the so-called human lithics at the aforementioned cave and Vale da Pedra Furada. Chiquihuite Cave's stone items do indeed appear to be naturally produced as opposed to capuchin-made for a multitude of reasons; I will address certain lithic items from Ardelean et al.'s (2020) Extended Data (Figure 5) to highlight some of the differences between the capuchin-lithics and Chiquihuite Cave's lithics.

Firstly, the cave's so-called "cores" do not appear to display signs of any particular reduction technique such as centripetal reduction or parallel reduction. Furthermore, all the flaked hammerstones of the capuchins that Tomos Proffitt and colleagues (2016) presented in their paper have at least one readily identifiable flaked surface—slightly concave in appearance—that happens to be surrounded by cortex. Due to the fact that cortex is by-definition a stone's external, weathered surface and that flake-detachment leaves behind a concavity on a core-stone (Shea 2013), a lithic item's flake-release surface and cortex are relatively distinct from one another. On the contrary, all the surfaces on any given "core" from Chiquihuite Cave appear to be enveloped with cortex, as indicated by the entirely weathered appearance. Unlike the capuchin lithic items, I cannot discern a significant difference in the texture and concavity/convexity between the different surfaces on any of the various "cores." The cave-site's purported cores do not demonstrate a separation between flake-release surfaces and the cortices; therefore, they do not fall within the realm of either human or capuchin lithics.

A lack of significant textural difference between stone-surfaces also applies to the stone items classified as "flakes" within Ardelean et al.'s (2020) Extended Data (Figure 5, items f-n). In stark contrast to the Chiquihuite Cave's "flakes," all of the capuchin flakes within Proffitt et al.'s (2016) figures that display flake-items have a clearly discernible ventral and dorsal surface, as demonstrated by the contrast between the weathered side of any given capuchin flake and smooth, glassy surface on the opposing side. Notably, photos of the two surfaces for any particular stone item in Ardelean et al.'s paper differ in their concavity/convexity relative to one another, suggesting that the photographs displaying the concave surface of a "flake" from Extended Data (Figure 5) are supposed to represent the ventral surface of that particular item. However, in contrast to their capuchin flake counterparts, the ventral surfaces of the supposed flakes from the Mexican cave are devoid of bulbs of percussion, errailure flakes, and negative ripple-marks radiating away from the proximal end. In short, the lithic items from Chiquihuite Cave do not align with the morphology of the capuchin lithics.

Most importantly, the northern-most region within which wild, non-human primates of the New World are able to reside is Southern Mexico (Alfaro 2017); all higher-latitude regions of the Americas relative to the neotropics have been devoid of primate life for roughly the last 26 million years (Samuels, Albright, and Fremd 2015). Thus, current fossil evidence corroborates the notion that non-human members of the primate tree would not have been the makers of the lithic items at the Mexican cave-site—situated within the northern half of the country—even if the stone items at the site were indicative of flint-knapping. In other words, the stones of Chiquihuite Cave do indeed appear to be the product of the forces of nature.

Support for Neotropical Primates as Creators of the Lithics at Vale da Pedra Furada

The lithic story behind Vale da Pedra Furada, however, may be more complex. Based on the stone item photographs that Eric Boeda et al. (2014) presented in their Figures 4 and 5, the cortex and surfaces of flake-detachment are distinct from one another on the lithic objects. In addition, the sketch within Boeda et al.'s (2014) Figure 4 makes the presence of a diffuse bulb of percussion and negative ripple marks radiating away from the proximal end readily apparent, which strengthens the notion that the flake-detachments were due to stone-knapping activities as opposed to natural forces. Furthermore, the items possess chipping along the edges of the stone-pieces, which suggests the presence of marginal flaking. This evidence is similar to that of capuchin lithics from the Oitenta site at Serra da Capivara National Park, which also demonstrates the presence of diagnostic lithic knapping signs such as bulbs of percussion and negative ripple marks.

Certain lithic items from the capuchin assemblage also bear resemblances to the marginal flaking appearance of the stone objects in Boeda et al.'s (2014) figures. One such example of a capuchin-made stone that is morphologically similar to marginally flaked tools from Boeda et al.'s paper is the item in photograph (b) from Proffitt et al.'s (2016) Extended Data (Figure 6). This stone item consists of dorsal cortex and a corresponding cortical platform like many of the stone flakes presented in Proffitt et al.'s (2016) paper. Furthermore, the stone item—oriented with the distal end up and proximal end down—has a noticeable bulb of percussion as indicated by the side-profile view of the item, which displays a bulge on the ventral surface's proximal end. Most importantly, the stone's left lateral margin in the dorsal-view (top-left image in photograph) displays signs of subtle chipping. Due to the chipping, this capuchin-made stone-piece appears as if it has undergone unimarginal retouch and is morphologically similar to the bottom-left lithic item in Boeda et al.'s (2014) Figure 5. The only key difference between the two stone-objects is that the capuchin stone in photograph (b) from Proffitt et al.'s (2016) Extended Data (Figure 6) qualifies as a side-scraper replica due to accidental chipping along the lateral margin, whereas the lithic piece in Boeda et al.'s (2014) Figure 5 looks similar to an end-scraper tool due to flake-detachment along the distal end.

In fact, Agustín M. Agnolín and Federico L. Agnolín (2023) utilized the existence of various morphological similarities between capuchin lithics and the exclusively unifacially-modified lithics from supposed pre-Clovis Brazilian sites—including Vale da Pedra Furada—to assert that capuchin monkeys may have been the true agents behind the purported artifacts at such sites. This is unlikely, however, due to the fact that capuchins have made substantial progress within the last few thousand years in the way they use stones. Therefore, it would make little sense for these primates to progress marginally for the several millennia preceding their known archaeological record. Rather, the more likely scenario is that some unknown—and perhaps extinct—primate could have possibly detached flakes and created the collection of chipped stones at the two sites.

A particular primate-genus of great antiquity in the Americas that has significant spatial overlap with the capuchins of Serra da Capivara National Park is *Alouatta*, known commonly as howler monkeys. Essentially, this group of primates arose sometime around 13.2 million years ago and proceeded to engulf many of the lands between southern Mexico and northern Argentina as it underwent multiple speciation events, thereby culminating in anywhere between 9 and 14 species (Doyle et al. 2021). Doyle et al.'s (2021) Figure 1 delineates the regions that the various species of howler monkeys currently occupy in Central and South America. Evidently, the geographic distributions of the species *Alouatta belzebul* and *Alouatta caraya* envelop much of the land that constitutes Serra da Capivara National Park, which itself subsumes Vale da Pedra Furada. According to Doyle and colleagues (2021), the inhabitation of these parts of the continent started fairly early as howler monkeys split into two major groups—the Mesoamerican howlers and the South American howlers—around 13 million years ago. Subsequently, the South American howlers initiated their colonization of the Amazon and Atlantic forests. Therefore, some obscure population of howler monkeys could have potentially engaged in lithic usage within the region of Vale da Pedra Furada as well as other archaeologically controversial Brazilian sites in the times preceding the onset of Clovis peoples and their respective lithic industry. Nonetheless, attempting to determine the likely non-human primate agents behind such sites is currently a mere supposition until further research is pursued in the domain of lithic use among neotropical primates other than capuchins.

Future Evolutionary Trajectory of Capuchin Stone Use

Based on both the multi-millennial antiquity of capuchin lithics and the advancements these simians have made over the course of time with their flaking activities, intentional stone tool modification for our fellow evolutionary relatives may not be as far-fetched as once thought. As previously discussed, various capuchins in different areas of South America have evidently been utilizing hammerstones for varying periods of time, and some have been inadvertently creating an assemblage of lithic items that share similarities with the basic, minimally modified lithic tools of humans. Capuchin-made stone items thus resemble the modified stone tools of our earliest, lesser-skilled hominin ancestors. One of the base-level attributes of human lithics is the use of hammerstones in order to detach pieces and reshape different stone items for particular purposes; in fact, fellow flint-knappers and archaeologists still utilize hammerstones in order to better understand the process behind toolmaking by our prehistoric ancestors. Currently, the particular capuchin-species known to produce flakes and core-replicas—bearded capuchins (*Sapajus libidinosus*)—do so without intent. As discussed within the first section of this paper, the objective of capuchins during percussion activities is to break open the target-stones attached to rock-beds, similar to their nut-cracking activities. In their efforts to break open cobble stones, some fragments of the percussed and percussor stone-objects chip off; these chipped items bear striking similarities to man-made stone flakes, which have conchoidal-fracture attributes. Although their original goal may not have been to detach flakes, the capuchins nonetheless utilize detached pieces for the purposes of licking them for mineral nutrition and/or utilization as hammerstones themselves, which demonstrates the existence of expedient stone-tool use among capuchin monkeys.

The Oldowan industrial complex is the staple of rudimentary stone tool technology with the creation of unifacial choppers, sharp-edge flakes, scrapers, and hammerstones. Deborah I. Olszewski’s (2016) text provides some illustrations depicting said tools from the Oldowan industry as well as a description of the technology in general (51). Capuchins have unwittingly managed to create conchoidal, sharp-edged flakes that would be equivalent to the unmodified flake-tools of Oldowan and pre-Oldowan hominins. Clearly, rounded hammerstones are the direct pre-requisite for the stone-on-stone percussion activities of capuchins at Serra da Capivara National Park; thus, these stone items are also in-line with Oldowan lithics. Furthermore, many flaked hammerstones from the capuchin assemblage that do not resemble core reduction sequences could easily be compared to the appearance of the most primitive Oldowan unifacial choppers. For example, the stone item in photograph (b) of Proffitt et al.’s (2016) Extended Data (Figure 3) has been reduced on one end as a result of flake-detachment. The reduced-end on this particular flaked hammerstone would be considered the chopping-end of a unifacial Oldowan scraper within a hominin archaeological context because the most basic Oldowan chopper requires the detachment of one flake from their surface (Olszewski 2016). Arguably, select capuchin-made lithics may even mimic the appearance of Oldowan scrapers; I hinted at this notion in the preceding section with the comparison between the stone item within photograph (b) of Proffitt et al.'s (2016) Extended Data (Figure 6) and the bottom-left lithic piece in Boeda et al.'s (2014) Figure 5, both of which display signs of unimarginal retouch. Taking into consideration the diagnostic characteristics already present on the capuchin-made flakes discussed earlier such as bulb of force and a flat striking platform, the right set of circumstances could potentially enable the capuchins to evolve towards formalized tool use. Consequently, the capuchins would enter their own equivalent of our early stone age.

As I can attest, the detachment of a smooth, flat striking platform takes some skill in itself. Therefore, capuchins seem to be relatively far along in their percussion-related motor skills. Based on their stone-activities from past to present, I attempted to conjecture what the future evolutionary route for capuchin monkeys could be. A potential next step in the evolution of capuchin stone use could entail truly processing the implications of their lithic activities and beginning the journey of utilizing those sharp-edge flakes that they detach during stone-on-stone percussion. If the capuchins were to begin intentional flake-detachment and subsequent flake-retouch, the technological innovation would make their daily foraging tasks significantly easier. In fact, Linda Marie Fedigan (1990) observed in her study that white-faced capuchins (*Cebus capucinus*) have also been incorporating meat consumption into their diet by hunting animals such as squirrels, lizards, white-crowned parrots, and magpie jays. Meat-consumption, however, is not exclusive to the gracile capuchin-species. Wild bearded capuchins also qualify as omnivores (Falótico 2022). Tiago Falótico explains that bearded capuchin monkeys periodically hunt and consume the following list of vertebrates (from most frequent to least frequent): lizards, birds, snakes, rodents, and bats. The processing of such food would be tedious without the use of tools to aid in the removal of unwanted parts such as feathers and bones from the prey's carcass. Marie Fedigan (1990) confirms this notion, as she herself uses the word "lengthy" to describe the act of meat-processing that the New World simians engage in. Therefore, the capuchin monkeys would benefit significantly if they began to modify the flakes that they unintentionally detach from hammerstones and target-stones and re-work those flakes into tools such as scrapers that could be used for skinning and dissecting their prey (Figure 1).

However, the benefits of intentional stone modification to capuchin monkeys extend beyond the realm of foraging. To reiterate my remarks near the end of the first section of this paper, the current method by which capuchins access the ventral surface of stones for mineral nutrition is haphazard; this is because they do not percuss stones with the intent to detach flakes, but simply to break open cobbles lodged within rock-beds. The act of intentional lithic reduction would therefore immensely benefit these simians, particularly the implementation of centripetal reduction. I delved into the benefits that the aforementioned reduction method could provide capuchin monkeys—namely, larger flakes to ingest a greater quantity of minerals present within the rocks—in the first section. Proffitt et al.'s (2016) video of a particular capuchin's percussion-activity clearly demonstrates that these simians waste valuable time relentlessly battering cobbles in the attempts to split open the stones. In order to speed up the process of flake-detachment and thus attain a consistent source of mineral nutrition, capuchin monkeys would have to engage in the production behavior that fellow anthropologist, Jay S. Reti (2016), has defined as "Oldowan Behavior A." This behavior essentially requires cognitive awareness to target the acute angles at the edges of a rock in order to consistently detach complete flakes.

Within controlled laboratory settings, capuchins have already demonstrated that they are more than capable of consistently producing a multitude of sharp-edged flakes through five different methods: 1) anvil percussion; 2) bipolar percussion; 3) hard-hammer percussion; 4) soft-hammer percussion; and 5) throwing a stone against the ground (Westergaard and Suomi 1995). Notably, the eleven capuchins that detached flakes were also able to modify the flaked pieces themselves, and three of the eleven subjects were able to make the cognitive leap to utilize the modified lithics as tools when cutting through the plastic of a container with a food reward. Granted, all the capuchins involved within the 1995 experiment by Gregory Westergaard and Suomi were previously trained in the practice of lithic modification, but the training does not discount the fact that stone tool reduction is evidently within the domain of capuchin intelligence.

Capuchins have progressed in their stone tool behaviors substantially, starting from Phase IV (tiny hammerstones and indiscriminate anvil sources) a few millennia ago, all the way to fairly heavy use of large stone anvils to extract food from less accessible structures in Phase II and the present day (ongoing in numerous places within modern-day South America). If the average intra-phase-duration of roughly a few hundred years at Caju BPF2 is indeed an indicator of capuchin behavioral and technological evolution, and if even one wild capuchin in the not-too-distant future is able to make the mental connection between flake-production and its use in various tasks, other capuchins could observe the innovator and possibly commence intentional lithic reduction themselves. Consequently, entire populations of capuchins could begin utilizing detached pieces and playing with rudimentary lithic modification over the next few centuries. As Tomos Proffitt and colleagues (2016) cite in their paper, previous research has demonstrated that chimpanzees accidentally break stones during nut-cracking-related activities, whereas capuchins intentionally break cobble stones but inadvertently detach flakes in the process. Furthermore, the authors assert that wild capuchins are the only living non-human primates to be able to replicate hominin lithics.

The range of lithic activities that wild capuchins currently engage in also happens to be the most varied among non-human primates, consisting of tasks such as: nut-cracking, stone-on-stone percussion, digging the soil for foraging purposes, and banging stones as an intimidation tactic (Falótico and Ottoni 2016; Falótico et al. 2019). In addition, capuchin lithic use has evolved significantly over the last three millennia in contrast to their chimpanzee counterparts, and the capuchins demonstrate greater behavioral flexibility through the use of varied hammerstone weights relative to chimpanzees and macaques.

Figure 1. A hypothetical capuchin in the future utilizing a modified flake-tool to process a dead bird. Illustration courtesy of P. S. Kahlon.

Therefore, capuchin monkeys are superior relative to other non-human members of the primate tree in their evolutionary pace, technological range, and adaptability. Moreover, capuchins may possibly be progressing in their use of stones at a substantially faster rate relative to our prehistoric hominin ancestors. Deborah I. Olszewski (2016) cites Oldowan lithic technology as having originated sometime between 2.6 million and 2.5 million years ago, while Sonia Harmand and coauthors (2015) present evidence for intentional pre-Oldowan stone tool use among the hominins around 3.3 million years ago. Based on those ages, the time that our ancestral species required to progress from pre-Oldowan to Oldowan-level tool-complexity is between 800,000 and 900,000 years. Proffitt et al. (2016) and Falótico et al. (2019), however, suggest a far shorter timeline for lithic progression among capuchins. Both groups of authors outlined the stone-type frequencies at their respective sites. Essentially, Falótico and colleagues (2019) state that 75 of the 122 stone items at the 3,000-year-old site, Caju BPF2, were complete hammerstones, whereas only 14 were flaked hammerstones, and only two were flakes (Supplementary Information: 1, 2). In contrast, Proffitt and coauthors (2016) state that the 111 lithics at the contemporary Oitenta site consisted of 44 flakes, 33 fragmented hammerstones, and only 16 complete hammerstones, among other stone items (Supplementary Information: 3). Simply put, the beginnings of stone-on-stone percussion activities among capuchin monkeys may have possibly been near the onset of Phase IV at Caju BPF2. If that is indeed the case, these primates have managed to begin inadvertently producing Oldowan-level stone-replicas over a span of only 3,000 years as opposed to the hundreds of thousands of years that it took our ancestors to begin engaging in the same level of lithic complexity.

Based on the small number of detached pieces and flaked hammerstones at Caju BPF2 in contrast with the majority of flaked pieces at Oitenta, I suggest the following possibility: the increase in stone-on-stone percussion activities among capuchin monkeys may possibly have been the result of an accidental discovery. Over the span of 3,000 years, capuchin monkeys in the general region of Serra da Capivara National Park continued working with stones to crack open food sources enclosed within shell-like structures, and they unwittingly detached lithic fragments during that process (as demonstrated by the Oitenta site). In more recent times, however, an individual capuchin may have decided to pick up a flake and lick its surface out of mere curiosity. As a result, this neotropical primate may have fortuitously ingested minerals such as powdered quartz, lichens, or silicon—which Falótico and colleagues (2019) cite as being a source of nutrition for the monkeys—and felt an odd sense of satiation. Fellow capuchins nearby may have witnessed this act and subsequently adopted the behavior of licking percussed-stone surfaces themselves. Such a scenario may explain the presence of frequent stone-on-stone percussion and corresponding flake-production at the Oitenta site in Serra da Capivara National Park. That being said, the hypothetical scenario that I described above to explain the emergence of recent capuchin lithic behavior may not necessarily be accurate. Nonetheless, bearded capuchins have the greatest likelihood among the living non-human primates to initiate deliberate stone tool-modification. However, the attempt to truly postulate when and how such a technological breakthrough could occur would require research into trigger factors that may allow capuchins to bridge the gap between expedient and formalized stone tool use. For example, further research could involve the investigation of potential future ecological changes (e.g., substantial habitat loss due to deforestation) that may cause the diet of capuchins to rely more heavily on meat-sources for sustenance. Consequently, the increase in meat-consumption may motivate certain capuchins to modify lithic pieces for the purposes of efficient food-processing.

Conclusion

Thus, the discussion within my paper demonstrates that the study of lithic behavior among non-human primates will enable us to clarify elements of human prehistory as well as to postulate on the shared planetary future of humanity and capuchin monkeys. First and foremost, bearded capuchins have the backing of a dynamic, 3,000-year-old lithic record, and their frequent-yet-inadvertent flake production in the present day culminates in stones that are similar to the fundamental, conchoidal properties of human lithic items. For that reason, capuchin lithics do not match with stones from Chiquihuite Cave in Mexico, which strengthens the notion that the stones at the Mexican site were naturally fractured. However, the stones of capuchins are less sophisticated, with traits such as exclusively unimarginal modification that align with the appearance of Oldowan tools and the purported pre-Clovis stones of Vale da Pedra Furada. Hence, some scholars (Agnolín and Agnolín 2023) are proponents of the notion that bearded capuchin monkeys have played a part in forming the stone items at archaeologically controversial sites in South America. As discussed within the second section, however, the significant lithic evolution of capuchins over the past three millennia and their spatiotemporal overlap with howler monkeys suggests that other primates could have played a part in the production of stone items at archaeologically controversial sites in the neotropics. Essentially, contemporary findings on capuchin lithic usage—whether intentional or inadvertent—have made the act of lithic reduction no longer as impressive as it once was. Capuchin stone use is re-shaping the narrative of humanity's evolutionary history in the Americas; consequently, non-human primate stone use may bear potential implications for the validity of certain Oldowan or pre-Oldowan contexts as well. Lastly, stone use among capuchin primates may possibly evolve toward intentional-modification within the span of centuries if future ecological changes such as a lack of plant food sources force the already-omnivorous *Sapajus libidinosus* to utilize sharpened stone tools for effective meat-processing. Such a short timeline for technological evolution may be more likely if the stark contrast between the frequency of flaked stones at the Caju BPF2 and Oitenta sites in Serra da Capivara National Park is truly indicative of lithic evolution over three millennia. We (humans) were living the Stone-Age lifestyle for roughly 3.3 million years if the lithic artifacts at the Lomekwi 3 site in Kenya are indeed hominin in origin (Harmand et al. 2015). Our fellow capuchins, on the other hand, may potentially have a far easier time navigating through the technological realm as soon as they begin utilizing formalized lithic tools, given their speedy track record.

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References Cited

Agnolín, Agustín M. and Federico L Agnolín. 2023. Holocene capuchin-monkey stone tool deposits shed doubts on the human origin of archeological sites from the Pleistocene of Brazil. *The Holocene* 33(2): 245–250.

Alfaro, Jessica Lynch. 2017. The Monkeying of the Americas: Primate biogeography in the neotropics. *Annual Review of Anthropology* 46: 317–336.

Andrefsky, William Jr. 2005. *Lithics: Macroscopic Approaches to Analysis*. Cambridge: Cambridge University Press.

Ardelean, Ciprian F., Lorena Becerra-Valdivia, Mikkel Winther Pedersen, Jean-Luc Schwenninger, Charles G. Oviatt, Juan I. Macías-Quintero, Joaquin Arroyo-Cabrales et al. 2021. Evidence of human occupation in Mexico around the Last Glacial Maximum. *Nature* 584: 87–92.

Boeda, Eric, Ignacio Clemente-Conte, Michel Fontugne, Christelle Lahaye, Mario Pino, Gisele Daltrini Felice, Niede Guidon et al. 2014. A new late Pleistocene archaeological sequence in South America: the Vale da Pedra Furada (Piaui, Brazil). *Antiquity* 88: 927–955.

Chatters, James C., Ben A. Potter, Anna Marie Prentiss, Stuart J. Fiedel, Gary Haynes, Robert L. Kelly, J. David Kilby et al. 2021. Evaluating Claims of Early Human Occupation at Chiquihuite Cave, Mexico. *PaleoAmerica* 8(1): 1–16.

Doyle, Esmeralda D., Ivan Prates, Iracilda Sampaio, Celia Koifmann, Wilson Araujo Silva Jr., Ana Carolina Carnaval, and Eugene E. Harris. 2021. Molecular phylogenetic inference of the howler monkey radiation (Primates: *Alouatta*). *Primates* 62: 177–188.

Falótico, Tiago, Tomos Proffitt, Eduardo B. Ottoni, Richard A. Staff, and Michael Haslam. 2019. Three thousand years of wild capuchin stone tool use. *Nature Ecology and Evolution* 3: 1034–1038.

Falótico, Tiago and Eduardo B. Ottoni. 2016. The manifold use of pounding stone tools by wild capuchin monkeys of Serra da Capivara National Park, Brazil. *Behaviour* 153(4): 421–442.

Falótico, Tiago. 2022. Vertebrate Predation and Tool-Aided Capture of Prey by Savannah Wild Capuchin Monkeys (*Sapajus libidinosus*). *International Journal of Primatology* 44: 9–20.

Fedigan, Linda M. 1990. Vertebrate Predation in *Cebus* capucinus: meat eating in a neotropical monkey. *Folia Primatologica* 54: 196–205.

Goodall, Jane. 1964. Tool-Using and Aimed Throwing in a Community of Free-Living Chimpanzees. *Nature* 201: 1264–1266.

Harmand, Sonia, Jason E. Lewis, Craig S. Feibel, Christopher J. Lepre, Sandrine Prat, Arnaud Lenoble, Xavier Boes et al. 2015. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. *Nature* 521: 310–336.

Mangalam, Madhur. 2018. The Biomechanics of Multi-Joint Posture and Movement Control in Wild Bearded Capuchin Monkeys Using Stone Hammers. PhD dissertation, University of Georgia, Athens.

Olszewski, Deborah I. 2016. *Archaeology and Humanity's Story: a brief introduction to world prehistory*. Oxford: Oxford University Press.

Potter, Ben A., James C. Chatters, Anna Marie Prentiss, Stuart J. Fiedel, Gary Haynes, Robert L. Kelly, J. David Kilby et al. 2021. Current Understanding of the Earliest Human Occupations in the Americas: evaluation of Becerra-Valdivia and Higham (2020). *PaleoAmerica* 8(1): 1–15.

Proffitt, Tomos, Lydia V. Luncz1, Tiago Falótico, Eduardo B. Ottoni, Ignacio de la Torre, and Michael Haslam. 2016. Wild monkeys flake stone tools. *Nature* 539: 85–88.

Reti, Jay S. Quantifying Oldowan Stone Tool Production at Olduvai Gorge, Tanzania. *PLOS One* 11(1): 1-24.

Samuels, Joshua X., Barry Albright, and Theodore J. Fremd. 2015. The Last Fossil Primate in North America, New Material of the Enigmatic Ekgmowechashala from the Arikareean of Oregon. *American Journal of Physical Anthropology* 158: 43–54.

Shea, John J. 2013. Lithics Basics. In *Stone Tools in the Paleolithic and Neolithic Near East*. Cambridge: Cambridge University Press.

Visalberghi, Elisabetta, Elsa Addessi, Valentina Truppa, Noemi Spagnoletti, Eduardo Ottoni, Patricia Izar, and Dorothy Fragaszy. 2009. Selection of Effective Stone Tools by Wild Bearded Capuchin Monkeys. *Current Biology* 19(3): 213–217.

Visalberghi, Elisabetta, D. Fragaszy, E. Ottoni, P. Izar, M.G. de Oliveira, and F.R.D. Andrade. 2007. Characteristics of hammer stones and anvils used by wild bearded capuchin monkeys (*Cebus libidinosus*) to crack open palm nuts. *American Journal of Physical Anthropology* 132(3): 426–444.

Westergaard, Gregory Charles and Stephen J. Suomi. 1995. The Stone Tools of Capuchins (*Cebus apella*). *International Journal of Primatology* 16(6): 1017–1024.